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# HIGHLY RELIABLE ENERGY-EFFICIENT GLASS COATINGS FOR PIPES TRANSPORTING ENERGY CARRIERS, LIQUIDS, AND GASES

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Comparative characteristics of known materials which are used to increase the longevity of steel pipes are presented. It is shown that glass enamel coatings provide effective protection from corrosion. The physical and technological characteristics of fused frits (water resistance, impact strength, microhardness) fall within the GOST 24405–80 limits.

The development of chemistry, metallurgy, power engineering, the oil and gas industries, communal-living developments, and other sectors of the economy depends on the use of pipelines. Therefore, there is a need for the use of building materials and (or) special coatings which are strong and have a high resistance to corrosion.

Pipelines cover 35% of the territory of our country, where 60% of the population lives, and accidents in pipelines present a direct hazard to the public, engineering works, and the environment. Steel pipes are used because of their high strength and good resistance to dynamical loads and bending forces. A serious drawback of such pipes is that they are subject to corrosion, which leads to substantial losses of metal, shorter longevity, greater roughness, and scaling of the inner surface. This greatly decreases the flow capacity of pipes, which requires additional energy consumption for transporting the flow medium. According to specialists at the Regional Sanitation Service (Ekaterinburg), the quality of the water which has passed through the city's piping system is substantially reduced: 30% of the water samples in the Verkh-Isetskii rayon, 50% in the Oktyabr'skii rayon, and 60% in the Kirovskii rayon are substandard and the iron content is 8 – 10 times higher than it should be.

Various types of coatings (sand-cement, lacquer, epoxy, polymer, metal, and others) are used to protect pipe surfaces from corrosion. But, experience in using such coatings has shown that they do not adhere well to the base metal and they do not provide reliable protection from chemical corrosion and abrasive wear. Corrosion inhibitors and steel with high resistance to corrosion also do not increase the longevity of pipes and equipment substantially. Thus, the anticorrosion technologies currently in use do not give the required longevity and reliable protection for piping systems.

Polymer pipes, primarily pipes made of thermoplastic materials (polyethylene, polypropylene, polyvinyl chloride), are quite widely used. However, thermoplastics are not nearly as strong or rigid and they are unsuitable for operation at high temperatures and cannot be laid across supports.

Reinforced plastics, called composite polymer materials (composites), have come into use in the last few years in Russia. The conventional methods of manufacturing composite pipes are based on the so-called positional principle, i.e., wrapping impregnated reinforcement made of fibers of aluminoborosilicate or aluminomagnesia glassceramic, where polyester, phenol and epoxy resins are used as the binder, or extrusion of a polymer onto a rigid metal wire framework. Metal-plastic pipes are a five-layer structure with polyethylene outer and inner layers, aluminum middle layer, and glue in the two intermediate layers.

However, problems which did not exist with steel pipes have appeared in systems consisting of polymer pipes. Because of their macromolecular structure, artificial materials are diffusion-permeable, i.e., gases (especially oxygen) can penetrate through pipe walls into the interior space and saturate the water flowing in the pipes. Numerous studies have shown that pipes made of polymer materials (polyethylene, polybutylene, and PVC) are easily penetrable and should not be laid in soils contaminated with hydrocarbons, including raw petroleum, oil, benzene, diesel fuel, kerosene, and other aromatic hydrocarbons and organic chemicals, or in locations where such chemicals are stored and used.

Pipes made of PVC and HDPE fail under tension over a period of time inversely proportional to the intensity of the stress. Polyethylene pipes are prone to brittle-like fracture, which combined with an increase of an external load (set-

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**TABLE 1**

| Indicator | Protective coating | | |
|---|---|---|---|
| | high-pressure polyethylene | epoxy resin (hardened) | silicate enamel |
| Density, g/cm$^3$ | 0.92 – 0.93 | 1.36 – 1.39 | 2.30 – 2.60 |
| Strength, MPa: | | | |
| tensile | 12 – 16 | 70 – 80 | 40 – 90 |
| compressive | 12.5 – 14.5 | 110 – 160 | 80 – 180 |
| Brinnel hardness, MPa | 4.3 – 5.2 | 1.0 – 1.2 | 40 – 80 |
| Water absorption over 24 h, % | 0.01 | 0.30 | Absolutely impermeable |
| Maximum applications temperature, °C | 80 – 100 | 100 – 110 | 300 – 500 |

tling of soil, excessive bending, pressure drops, hydraulic shocks, increase of the operating temperature, and so on), results in failure.

Together with many positive properties, pipes made of polymers age with time and lose their strength (relaxation phenomenon). This is characteristic for all polymers. A distinguishing feature of polymer pipes is that they age along the entire mass, while corrosion of steel pipes starts at the surface. Plastic pipes fail immediately and completely, while flaws which can be fixed (for example, by welding) form in metal pipes. As a polymer ages and its structure breaks down, the products of decomposition interact with the transported liquid and are partially carried by the liquid to the end and partially settle on the pipe wall, resulting in scaling of the pipe. The principal technical characteristics of protective coatings are presented in Table 1.

Of the existing coatings for protecting metal articles from corrosion, the most reliable and versatile coatings are silicate-enamel coatings, which combine the strength properties of a metal with the high chemical stability of silicate enamels.

One way to improve water supply systems is to use pipes with a silicate-enamel coating. Such a coating, being a composition based on silicates, is distinguished by high chemical, thermal, corrosion, and abrasion resistance, prevents deposits from forming on the pipe walls, operates reliably at temperatures from – 50 to + 350°C, protecting from internal corrosion pipes carrying corrosive products (including acid and alkali, with an appropriate composition of the enamel), and decreases the hydraulic resistance of pipes, increasing their flow capacity.

Protective silicate-enamel coatings are of the reinforced type and have provided anticorrosion protection for pipes for at least 50 years. Compared with the new steel pipes, pipes coated with silicate enamels make it possible to decrease pressure losses and energy consumption by a factor of 1.55, and this ratio can only increase since steel pipes are subject to scaling the longer they are used. Enamel-coated pipes are highly hygienic, since they essential do not interact with the transported liquid and do not dissolve in it. The flow capacity of enamel-coated pipes increases by a factor of 1.29, which is equivalent to a 10 – 12% decrease of the pipe diameter. Pipes with silicate-enamel coatings will make it possible to decrease the total cost of a piping network by at least 58% (taking account of the different operating times of such pipes).

The proposed, new, highly reliable, and energy-efficient composite pipes will provide stable and reliable operation of equipment and systems in communal-living developments as well as ecological and fire safety, and ensure that the transported product remains hygienic.

Silicate-enamel coatings are most effective and promising. The grade of the enamel chosen depends on the type of media being transported and the presence of acids, alkali, salts, and mechanical impurities in them. The thickness of the coating is 300 – 500 μm and the operating temperature ranges from – 150 to + 400°C.

During operation enamel-coated pipes are exposed to a water medium, impact and heat loads, and wear so that we studied their mechanical properties and the chemical resistance of the coating.

The water resistance of the enamels was determined with respect to distilled water by the surface method (GOST 24788–81). The data in Table 2 show that the compositions 4 and 5 have the highest resistance to water. We explain this by the lower content of $SiO_2$ and the higher content of metal oxides in the enamels 2 and 3 than in the enamels 1, 4, and 5.

The thermal conductivity and elastic modulus were determined by the method of [1] and the resistance to acids and alkali according to GOST 27180–86.

**TABLE 2**

| Enamel | Water resistance, mg/cm$^2$ | Thermal conductivity, W/(m · K) | Impact strength, J | Elastic modulus, GPa | Micro-hardness, MPa | Acid resistance, % | Alkali resistance, % |
|---|---|---|---|---|---|---|---|
| 1 | 4.35 | 0.74 | 1.82 | 60 | 5570 | 99.26 | 97.6 |
| 2 | 0.32 | 0.82 | 5.00 | 57 | 6650 | 98.87 | 92.4 |
| 3 | 0.19 | 0.87 | 5.70 | 54 | 6800 | 98.75 | 94.7 |
| 4 | 1.22 | 0.90 | 6.82 | 72 | 6800 | 98.60 | 95.5 |
| 5 | 1.38 | 1.11 | 7.90 | 75 | 6850 | 98.76 | 95.8 |
| 6 | 0.59 | 1.36 | 7.30 | 78 | 7150 | 98.74 | 96.8 |

The impact strength of the enamels was tested according to GOST 24788–81. The material tested was borosilicate alkali-containing enamel with iron and manganese oxide content ranging from 12 to almost 30 wt.%. Impact strength is one of the most important characteristics of a coating because pipes are exposed to large impact loads. The microhardness of the coatings was measured with a PMT-3 microhardness meter. The microhardness of each coating

was measured 10 times and the average values were taken. The results of these tests are presented in Table 2.

It is evident that the impact strength of the enamels in the second series is higher than that of the enamels in the first series, especially enamel 1. It is known [2] that the impact strength of an enamel coating depends on the degree to which it has crystallized and on the adhesion between the enamel and the metal. For all enamels tested, chipping under a strong impact occurred not along the metal – enamel boundary but rather along the enamel layer. It can be concluded from this that all enamels have quite good adhesion to metal and the impact strength depends only on the degree to which the coating has crystallized.

X-ray diffraction analysis showed that in this series of enamels, after heat treatment at the calcination temperatures, the enamel 1 did not exhibit any peaks characteristic of magnetite, while the enamels 3 – 6 did exhibit such peaks, which became sharper as the content of iron and manganese oxides increased. It can be concluded from the data in Table 2 that the increase in the thermal conductivity, microhardness, impact strength, and elastic modulus is due to the crystallization of the enamels. The data obtained show that the degree of crystallization is higher in enamels with a high content of iron and manganese oxides. At the same time, as the fraction of the crystal phase in the enamel increases, the resistance to water, acid, and alkali decreases as a result of the increase in the content of iron and manganese oxides.

The compositions (3 and 4) with a low content of iron and manganese oxides are recommended as enamels for use in pipes.

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